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CFRP STRENGTHENING OF CIRCULAR CONCRETE SLAB WITH AND WITHOUT OPENINGS

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ABSTRACT

This paper includes an investigation and experimental testing of R.C circular slabs with and without opening and strengthens with CFRP sheets, CFRP bare, and both. Normal concrete (NC) and self-compacted concrete (SCC) were used to cast the slabs. The experimental part includes testing of fourteen circular slabs divided into four groups having diameter of 1200mm and thickness of 80mm. Three types of strengthening used; the first type is CFRP sheets only, the second type is CFRP bar only, and the third type is the combination of the two types of strengthening (i.e. CFRP sheets and CFRP bar together). The use of CFRP sheets delays the appearance of the cracks by (14.75%-51.76%) compared with slabs without strengthening. The experimental results showed that the opening existence in the slabs without strengthening reduces the ultimate load carrying capacity by (24.98%-27.77%) compared with slab without opening, and the higher reduction in the ultimate load occurs in the slab (S2S2) by (30.55%) which is strengthen with CFRP sheets and contains two square opening. The increase in load carrying capacity of slab due to strengthening was (3.72%-26.18%) compared with the same slabs without strengthening. The optimum a result of strengthening was in the slabs strengthen by compensation of CFRP sheets and CFRP bar by increasing percentage (18.31%-26.18%) compared with unstrengthen slabs with openings. The numerical analyses present three-dimension nonlinear model by using computer program (ABAQUS 6.13).

Key words: Circular Slab, CFRP Bar, CFRP Sheet, Uniformly Distributed Load and Strengthening

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1. INTRODUCTION

The roof covering, the base slabs and circular raft foundations in the circular water tanks are the examples of circular slabs. The roof coverings of circular auditoriums are also the circular slabs. The pump houses built-over the tube wells have circular slabs for roof covering. The circular slabs are also provided over traffic control posts at road crossings. The elastic analysis for isotropic circular panels carrying symmetrical loads is dealt in standard text books of theory of plates and shells, For circular panels (in plan) simply supported or fully fixed along the circumference and carrying symmetrically distributed loads. The expression for total bending moments which should be provided for across each of two diameters mutually at right-angles have been derived by S. Timoshenko and S. Woinowsky-Krieger[1]. The circular plate carrying loads symmetrically distributed about the axis perpendicular to the plate through its center, the middle plane of the plate deflects symmetrically. The deflections at all the points equally distant from the center of plate will be equal It is sufficient to consider the deflections in one diametrical section through the axis of symmetry. The circular slabs carrying uniformly distributed load deflects in the shape of a saucer. The radial and circumferential stresses develop in the slabs. The radial and circumferential cracks are always seen near the center of slabs. The convex and concave surfaces of the saucer surface carries tensile and compressive stresses, respectively, the reinforcement is provided in the radial and circumferential directions , Instead of this, the reinforcement is also provided into two directions mutually at right-angles. Normally. the reinforcement for the positive bending moments is provided in two directions mutually perpendicular near the center and the reinforcement for the negative bending moments near the edge should be provided by radial and circumferential bars. n general, the radial and tangential moments vary according to the position being considered. A circular slab may therefore be designed by one of the following elastic methods.

2. CONCRETE SLAB WITH OPENING

Suspended RC solid slab has been widely used for the multi-story building and large openings are required by lift, stairways and elevator shafts. Meanwhile, small openings are wanted in the slab to pass the mechanical and electrical services such as plumbing, heating and ventilating risers. The influence of small openings in the structural is not often considered in view of the ability of the structure to redistribute stresses. However, the large openings, the static system may be changed when it needs to remove a significant amount of concrete and reinforcement bar. This may lead to decrease in ability of the structure to resistance the applied loads and the structural requirements[2].

3. OBJECTIVE OF THE STUDY

The objectives of the present work are:

- Investigating experimentally the effect of openings on the flexural capacity of circular RC slabs.
- Investigating. Experimentally, the behavior of circular RC slabs with and without opening strengthened with (CFRP sheet) and (CFRP bar) subjected to static uniform loading.
- Investigating the effect of location and shape of openings on circular RC slabs.
- Finite element analysis by using ABAQUS program and comparing the results with those obtained experimentally

4. MATERIAL PROPERTIES

4.1. Cement

Ordinary Portland cement of Tasloja-Keresta mark was used in casting all specimens. The cement complied with the Iraqi specification No. 5/1984[3].

4.2. Fine Aggregate (Sand)

Natural sand from (Al-Akaidur) region was used throughout this work. Results indicated that the grading, clay content and sulfate content are conformed to the requirements of the limits of the Iraqi Specification No.45/1984[4]

4.3. Coarse Aggregate (Gravel)

Crashed gravel from Badra region was used throughout this work within maximum size of (17mm); the crushed gravel coarse aggregates were washed and stored in air to dry the surface.

4.4. Water

Ordinary clean tap water was used for casting and curing all the specimens as well as for washing the fine and coarse aggregate.

4.5. Filler Materials

Limestone powder which has been brought from local market was used to increase the amount of powder content (cement + filler) in the SCC mixes to increase the density and workability of the SCC.

4.6. Steel Reinforcement

Deformed steel bars (8mm) in diameter were used as reinforcement to test slab specimens obtained from China production. The steel reinforcement was tested according to ASTM-A615/A-615M-05a.The yield stress and the ultimate strength is summarized in Table (1). The tensile tests were performed using the testing machine available at the Material Laboratory of the Material Engineering Department at Babylon University.

Table 1 Properties of Steel Reinforcement*

Nominal diameter (mm)	**Measured diameter (mm)**	**Pattern**	**Yield Stress fy MPa**		**Ultimate Strength f_u MPa**		**Modulus of elasticity of steel (GPa) E_s**
			result	**limit**	**result**	**limit**	
8	7.6	C**	567	520	646	690	200

* The value is an average of three specimens.

** Deformation pattern C consists of diagonal ribs inclined at an angle of 60 degrees with respect to the axis of the bar

4.7. Super-plasticizer (SP)

Sika-ViscoCrete-5930 High Performance Super-plasticizer Concrete Admixture

4.8. Carbon Fiber Reinforced Polymer (CFRP) and Sikadur-330

The CFRP sheet used in the strengthening opening application was SikaWarp Hex-230C unidirectional flexible sheets. The structural adhesive paste used for bonding the SikaWarp Hex-230C sheets to the concrete substrate was Sikasdure-330 which is high-modulus high-strength two component (A and B) products; see Figure (1-A).

Sikadur-330 is a two parts; solvent free, thixotropic epoxy based impregnating resin / adhesive. The mixing Part A: part B = 4: 1 by weight. When using bulk material, the exact mixing ratio must be safeguarded by accurately weighing and dosing each component.

4.9. Carbon Fiber Reinforced Polymer bar (CFRP bar) and Sikasdure-30

The CFRP bar used in the strengthening opening application was Aslan 201 bars. The structural adhesive paste used for bonding the Aslan 201 bars to the concrete substrate was Sikasdure-30 which was high-modulus, high-strength two component (A and B) products; see Figure (1-B).

Figure 1 Strengthed Materal

5. CONCRETE MIX

In this work, two types of concrete mix were used

5.1. Self-compact concrete SCC

5.2. Conventional Concrete (Normal Concrete NC)

6. SPECIMENS DESCRIPTION

6.1. The Molds Preparation

The circular slab models were cast in plywood mold to give a circular slab model with diameter 1200 mm and thickness 80 mm where aspects of the mold were made of a plate thick 2 mm.

6.2. Specimens Design

The slab model was reinforced with 8mm diameter steel reinforcement for positive reinforcement in the two orthogonal directions and circumference reinforcement. Therefore, the reinforcement were placed at the bottom face of the slab .The reinforcement was near to the bottom face of slab uniformly spaced at 150mm c/c. This arrangement of slab reinforcement gave steel ratios (ρ =0.00284).

6.3. Supporting and Loading System

Supporting system and load consisted of three major pieces (supporting base, load system and plate loading), as shown in Figure (2), and saturated sand above the slab with thickness 13 cm to the transfer loads from plate loading to the slab to make a uniform load.

Figure 2 Supporting Base and Load System

7. SPECIMEN IDENTIFICATION AND STRENGTHENING SCHEMES

In this research 14 samples were used and divided into two groups the first group of 12 Specimen of SCC; the second group of 2 Specimen of normal concrete. Specimens can be classified according to the type of concrete used or the type and form of strengthening of opening or the opening in the Specimen. All areas of the opening in the Specimen equal with the change of the shape of the opening and its division in to two opening have the same area for on opening.

In this study, we relied on classifying Specimens according to the shape of the opening.

Based on this classification become our four groups:

Group 1: contains a single specimen without opening.

Group 2: contains 7 specimens with a square opening.

Group 3: contains 4 specimens with a circular opening.

Group 4: contain 2 specimens each model has two holes in a square shape.

Specimen shapes and Strengthening Schemes are shown in Figure (3).

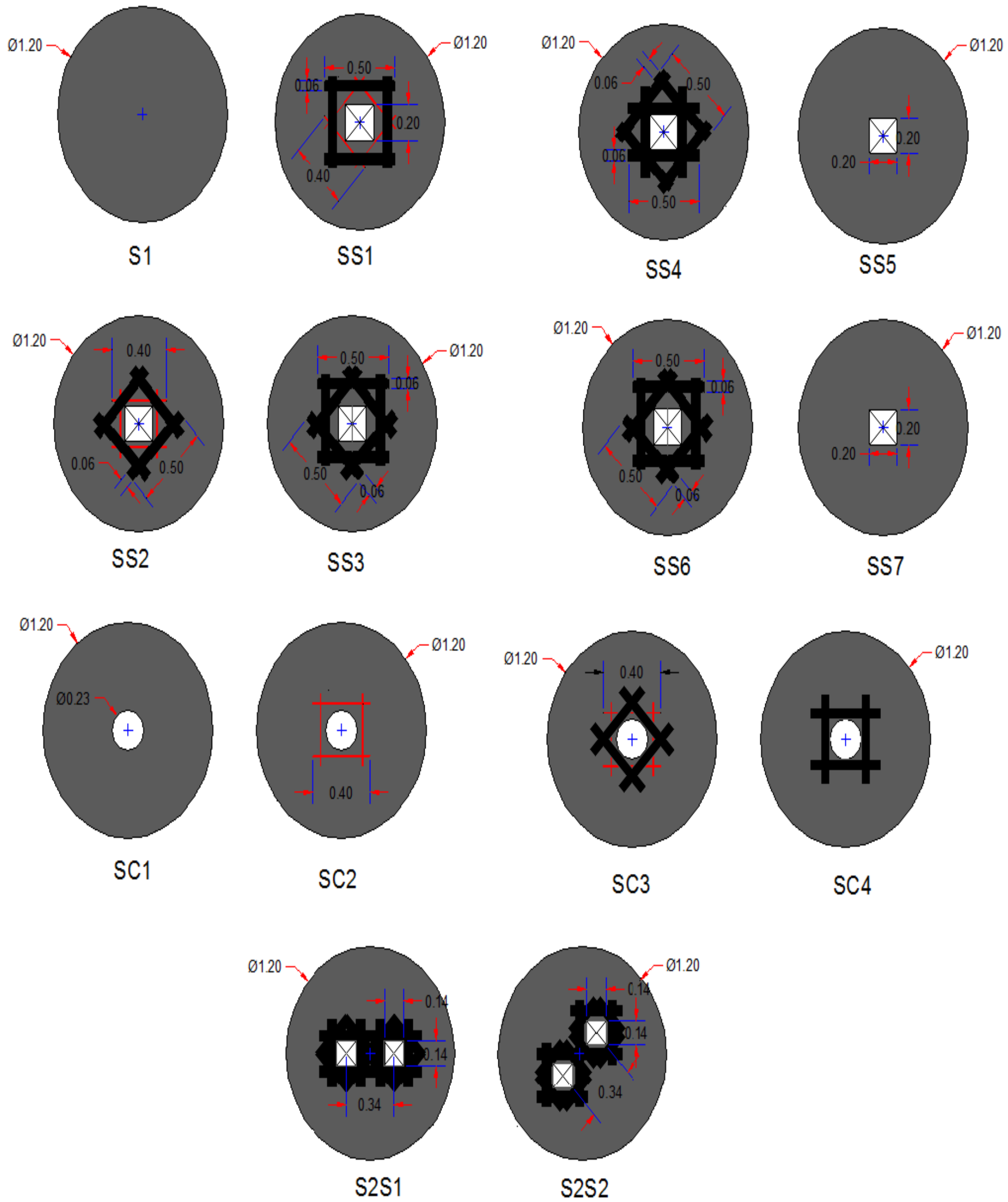

Figure 3 Specimen Shapes and Strengthening Schemes

8. CONCRETE CASTING AND CURING

The internal surfaces of cube, cylinder, prism, circular molds were well cleaned and oiled to avoid adhesion with concrete after hardening. Afterwards, the reinforcement was placed in the right position for all slab molds. 12 molds were filled with SCC, concrete in one layer without compaction, and 2 molds were filled with NC with compaction in two layers.

9. MECHANICAL PROPERTIES OF HARDENED CONCRETE TESTS

In the hardened phase, the tests done were destructive only. The destructive tests were compressive strength (cube & cylinder), splitting tensile strength, modulus of rupture, and stress-strain relationship (static modulus of elasticity). All the hardened properties of concrete for all specimens for all mix types at age 28 days are listed in Table (2).

Table 2 Hardened Properties for all Mixes of Concrete

Mechanical Property	f_{cu} (MPa)	f'_c (MPa)	f_r (MPa)	f_{ct} (MPa)	E_c (GPa)
S1	63.4	52.1	6.23	4.53	33.92
SS1	59.2	53.4	5.89	4.12	34.35
SS2	58.7	51.6	5.95	4.22	33.76
SS3	72.1	55.6	6.67	4.38	35.05
SS4	66.5	49.7	6.67	4.67	33.13
SS5	62.4	48.3	6.11	3.92	32.66
SS6	35.8	27.7	4.3	3.14	24.74
SS7	32.4	26.9	4.1	3.23	24.38
SC1	65.0	49.3	5.85	4.23	33.00
SC2	68.3	53.6	6.24	4.42	34.41
SC3	58.2	48.4	5.65	3.82	32.70
SC4	64.3	52.3	6.32	4.45	33.99
S2S1	76.3	58.7	7.12	4.84	36.01
S2S2	71.2	52.4	6.37	4.20	34.02

10. EXPERIMENTAL PROGRAM

These experimental variables included in this study were focused mainly on the shape of opening, type of concrete (SCC or NC) and type of strengthening (CFRP straps, CFRP bar or CFRP straps and CFRP bar) fourteen circular slab specimens were investigated in this study to observe the flexural behavior of the slab.

To study the variables indicated above, ten of the fourteen slab were strengthened with CFRP strips and CFRP bar and four slab specimen were tested without strengthening (control) (the first with SCC and without opening, the second with SCC with square opening (200 mm), the third with SCC with circular opening (d=230 mm) and the fourth with NC with square opening (200 mm)).

All the reinforced concrete slabs were of the same diameter (1200 mm) and thickness (80 mm) and reinforced identically. The amount of CFRP strips and CFRP bar constant in all slabs under strengthening to compare between similar slabs.

All areas of the opens in the slab equal with change the shape or number of the opening.

Test results were analyzed based on cracking behavior, vertical load–deflection and strain of concrete and CFRP up to failure, strain distribution of the reinforced concrete slab along two orthogonal directions (r & θ direction)in tension face.

11. EXPERIMENTAL RESULTS OF SLAB MODELS

11.1. General Behavior

All specimens were designed with a flexural reinforcement ratio of (0.00284) with a clear cover to the reinforcement of 15mm, which is higher than the minimum reinforcement ratio required (0.0018) by ACI building code' (ACI-318, 7.12.2.1)

11.2. First crack

The first cracking loads (**Wcr**) which were obtained from experiments. Generally, the visible first crack load of all the specimens varied from (13.6%) to (25.5%) of the experimental average ultimate loads.

11.3. Ultimate Loads and Failure Modes

Table (3) provides a comparison for slabs with one and two square openings and circular opening, effects of the strengthening by using CFRP sheets and CFRP bar on increasing the ultimate loads with respect to unstrengthen slab (control solid slab). The comparison was based on the ratio of the measured ultimate load for each slab with respect to the ultimate measured load of the control solid slab.

Table 3 The ultimate load capacity

Group Number	Specimen Symbol	Ultimate load (kN/m^2)	Difference in ultimate load compared with S1 (%)	Increase in ultimate Load For Group (%)
1	S1	236.6	----	----
2	SS1	223.5	-5.54	+25.92
	SS2	210	-11.24	+18.31
	SS3	190.7	-19.40	+7.44

Group Number	Specimen Symbol	Ultimate load (kN/m^2)	Difference in ultimate load compared with S1 (%)	Increase in ultimate Load For Group (%)
	SS4	187.4	-20.79	+5.58
	SS5	177.5	-24.98	Control
	SS6	184.1	-22.19	+3.72
	SS7	170.9	-27.77	-3.72
3	SC1	171.9	-27.35	Control
	SC2	203.8	-13.86	+18.56
	SC3	216.9	-8.33	+26.18
	SC4	180.8	-23.58	+5.18
4	S2S1	190.6	-19.44	----
	S2S2	164.4	-30.52	----

Furthermore, the measured of the deflection at the ultimate load for each slab at two points (at distance 12 cm from center at distance 35 cm from center).

The slab strengthening by (CFRP bar and CFRP sheet) with square opening (SS1) gave the best result compared with solid slab, the decreases in ultimate load (-5.54 %) but the same properties slab without strengthening (SS5), the decreases in ultimate load (-24.98 %), this means this type of strengthening is the best.

11.4. Cracking Patterns

The cracking behavior of each group slab specimen was discussed in the following:

1. **Group 1:** contains a single specimen without opening S1 (control) are shown in Figure (4)

Figure 4 Cracks pattern for slab S1

2. **Group 2:** contains 7 specimens with a Square Opening are shown in Figure (5)

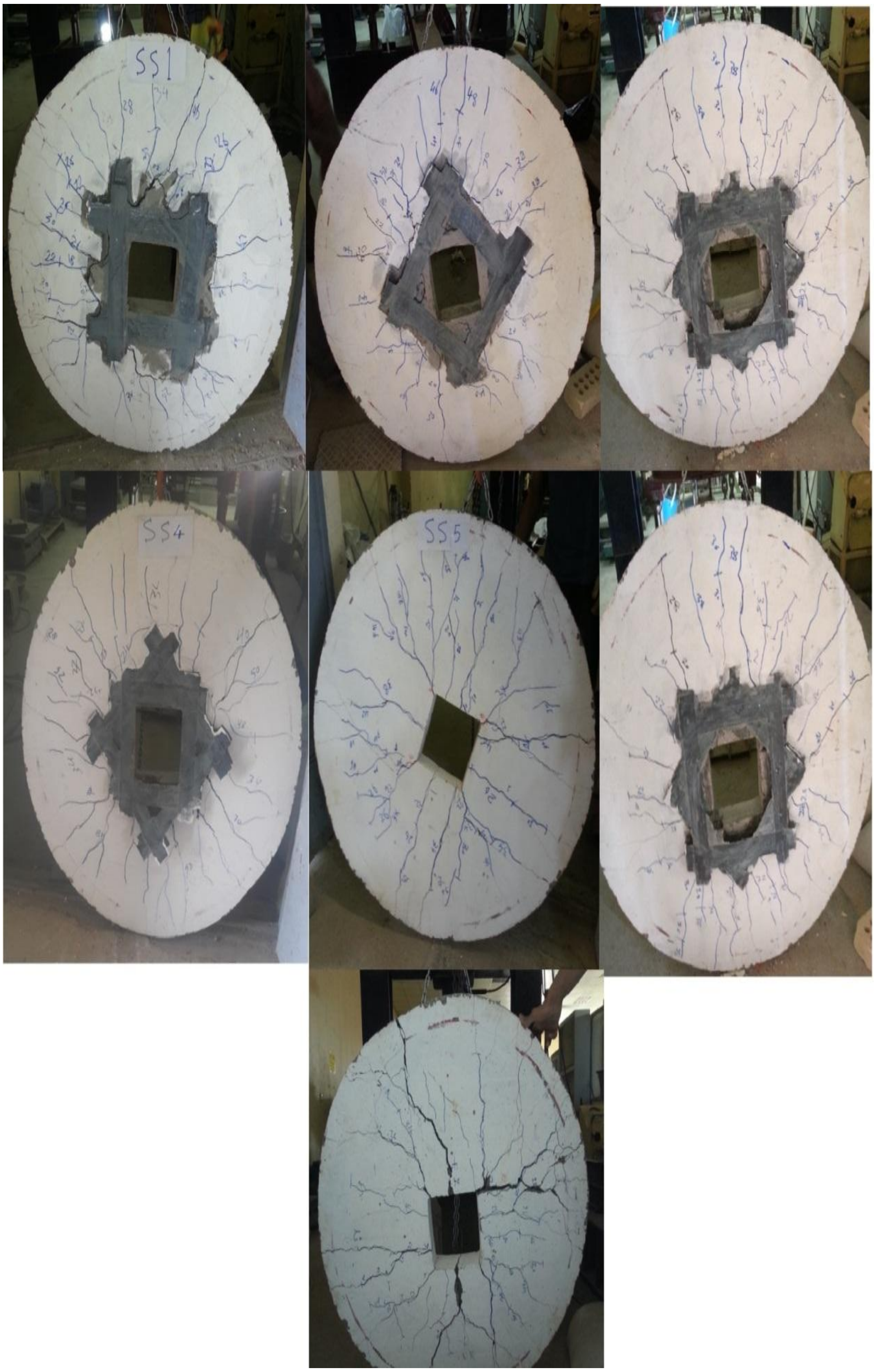

Figure 5 Group 2

3. **Group 3:** contains 4 specimens with a circular opening are shown in Figure (6).

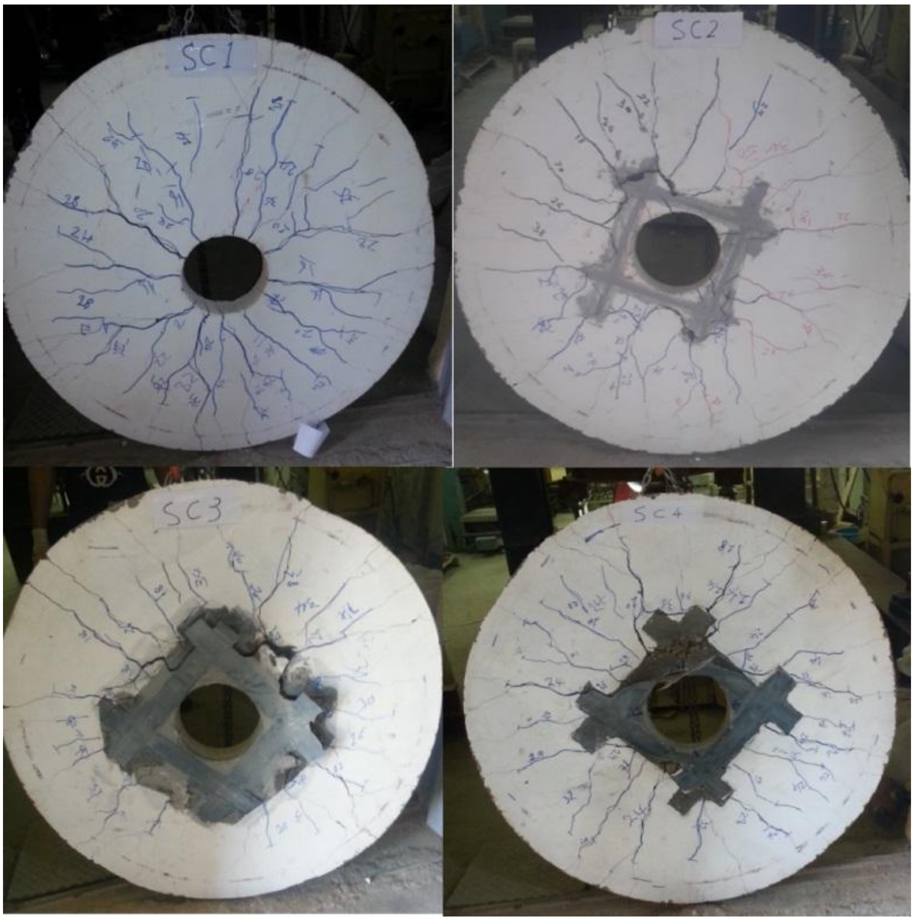

Figure 6 Group 3

4. **Group 4**: contain 2 specimens each model has two holes in a square shape, are shown in Figure (7).

Figure 7 Group 4

12. FINITE ELEMENT METHOD RESULTS

12.1. Results of Finite Element Analysis

Group 2: contains 7 specimens with a Square Opening

⋈ Circular slab (SS1): The numerical load-deflection curves were compared with the experimental results, as shown in Figure (8). The first crack of FE appeared at (38.9 kN/m^2), which was less than the experimental of (41.1 kN/m2) by about (5.7%).

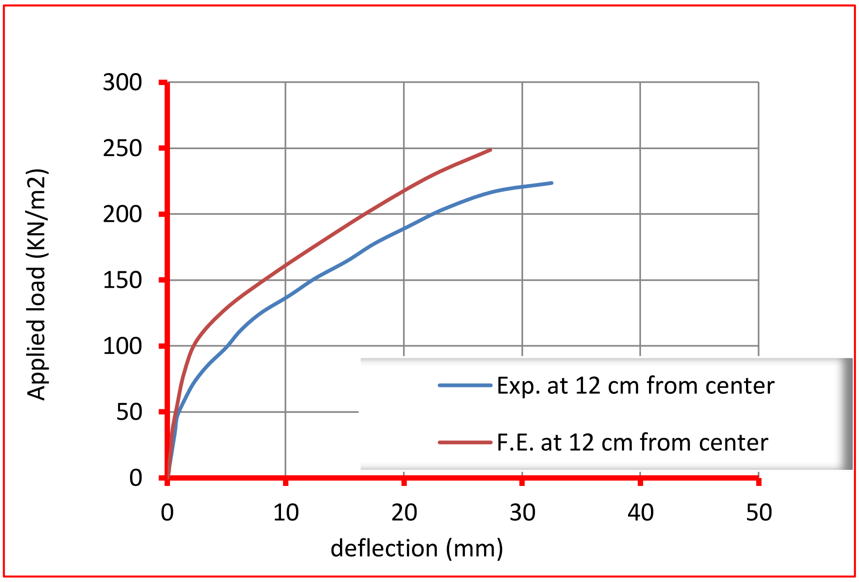

Figure 8 Load-deflection curve for slab SS1.

The F.E result was stiffer than the actual slab. The ultimate load for the F.E. (248.7 kN/m^2) was more than the experimental (223.5 kN/m^2) by about (8.5 %). The ultimate deflection from F.E. (27.3 mm) was lower than the experimental (32.5 mm) by about (19 %). Figure (9) shows the plastic strain at the ultimate load and the crack pattern.This form and the type of strengthening that was used in the slab (SS1) gave the best results in increasing the slab carry compared to other forms of strengthening.

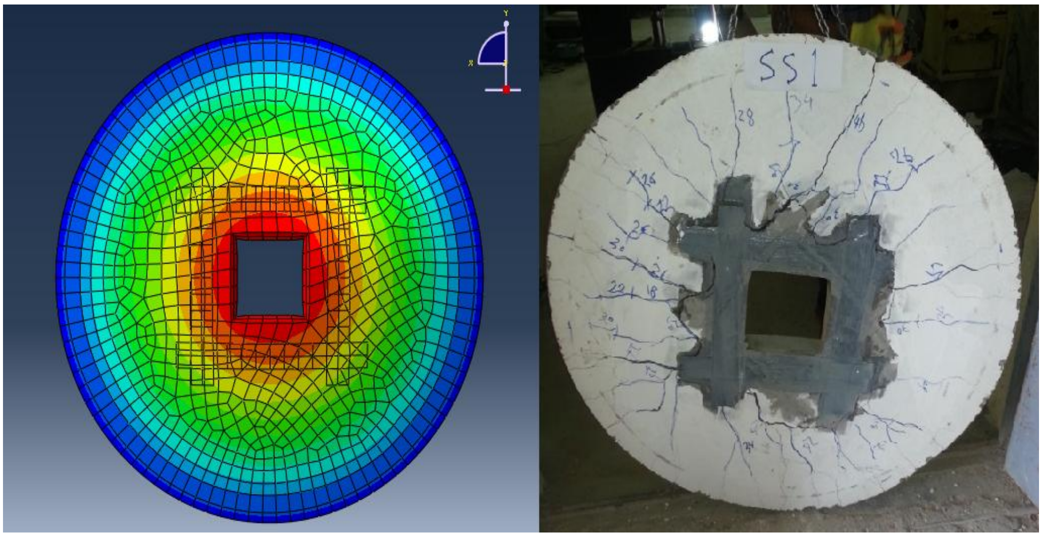

Figure 9 Plastic Strain and Crack Pattern for Slab (SS1) at Failure

12.2. Ultimate Loads and Ultimate Deflection

A comparison between the theoretical and experimental values of the first crack load, ultimate load and ultimate deflection for all slabs models as shown in Table (4). The table shows a good agreement between the theoretical and the experimental results.

Table 4 Experimental and theoretical cracking load, ultimate load and max. deflection

Slab Symbol	Ultimate Load (kN/m2)		F.E./EXP. (%)	Max. Deflection (mm)		F.E./EXP. (%)
	Exp.	F.E		Exp.	F.E	
S1*	236.6	256.8	108.54	30.4	28.4	93.4
SS1	223.5	248.7	111.28	32.5	27.3	84.00
SS2	210	236.4	112.57	30	25.3	84.33
SS3	190.7	207.4	108.76	24.1	21.2	87.97
SS4	187.4	212.3	113.29	25.8	23.4	90.70
SS5*	177.5	190.3	107.21	22.3	24.6	110.31
SS6	184.1	195.8	106.36	22.3	20.6	92.38
SS7*	170.9	177.6	103.92	20.1	22.5	111.94
SC1*	171.9	180.5	105.00	21.3	19	89.20
SC2	203.8	220.4	108.15	26.1	21.5	82.38
SC3	216.9	231.7	106.82	25.1	20.3	80.88
SC4	180.8	203	112.28	26.9	24.8	92.19
S2S1	190.6	204.2	107.14	23.9	21.3	89.1
S2S2	164.4	173.4	105.5	19.2	19.5	101.56

13. CONCLUSIONS

1. The experimental test results confirmed that the strengthening technique of (CFRP bar and CFRP sheet) system is applicable and can increase the moment capacity for strengthened of R.C circular slab. In this study, the ultimate load capacity of the strengthened slabs ranged between 5.18% to 25.92% over the ultimate load capacity of the reference (unstrengthen) slab.
2. The presence of openings in slabs showed a decrease in stiffness. In this study, slab with two openings (S2S2) gave the minimum results in the ultimate load (-30.52 %) compared with the control solid slab.

3. Using (CFRP bar and CFRP sheet) strips in R.C circular slabs with openings had a significant effect on the ultimate strength and deflection of tested slabs. The high modulus of elasticity of CFRP found to be an important factor in decreasing the deflection of R.C circular slabs.
4. R.C circular slabs with openings and strengthened by (CFRP bar and CFRP sheet) showed an increase in ultimate load capacity. This increase was about (26.18% - 18.13%) for slabs strengthened by the (CFRP bar and CFRP sheet), (5.18% - 7.44%) for slabs strengthened by (CFRP sheet only) and (18.56 %) for slab strengthened by the (CFRP bar only), compared with the control slab (without strengthening) in the same group.
5. The presence of CFRP sheet at the bottom tension zone surface reduced the tensile concrete strains, and this reduction was reflected to strains in the bottom tension steel bar reinforcement (i.e., reducing the tension steel bar strains), and this means increasing the tension strength and some tensile stresses would be carried out by CFRP sheets
6. The debonding in circular slab specimens was very sudden and the only indication of incipient failure was few popping sounds as the debonding cracks propagated quickly to the end of the sheet. The clear message of the experimental results were that the premature and brittle nature of bonding failure may reduce the level of safety of the strengthened R.C circular slabs by decreasing its ductility.
7. The three-dimensional finite element model used in the present study was able to simulate the strengthened reinforced concrete circular slabs with (CFRP bar and CFRP sheet). The cracking loads, ultimate deflection and predicted ultimate loads were close to that measured during the experimental testing with the maximum difference ratio in the ultimate load was lower than (13.29%) for all the tested and analyzed slabs.

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